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The Sugar We Get From Milk

C. H. Fisher

Milk sugar, or lactose, is one of the naturally occurring sugars. It differs from sucrose, dextrose (or glucose), and other natural sugars in several respects. It is less sweet. It dissolves slowly in water. The amount that can be dissolved is smaller.

Lactose is present in the milk of all mammals to the extent of 2 to 8.5 percent; it is uniquely the sugar of the animal kingdom. Nutritionally it is highly important; because it is in milk, it is consumed in larger quantities than any other sugar except sucrose.

The cow's milk produced annually in the United States contains approximately 6 billion pounds of lactose. Because only a relatively small proportion of it is separated, however, its production in purified crystalline form is far below that of crystalline sucrose and dextrose.

Lactose was isolated and first understood as a separate milk component by the physiologist Fabritius Bartolettus in 1633. Some time later commercial production of lactose was started in Switzerland. For many years that country produced the only sizable quantities, but before the close of the nineteenth century most of the world's supply was made in the United States near St. Charles, Ill. Probably an even greater proportion of the world's current lactose production is in this country.

The quantity of lactose produced annually in the United States increased gradually until it became constant at about 7 million pounds during the several years preceding the development of penicillin. After workers in the Northern Regional Research Laboratory found that lactose is the best sugar for penicillin substrates, the need for this sugar increased at such a rate that production trebled in a few years. As penicillin became more and more important the manufacture of lactose went up from 7.6 million pounds in 1943 to 23 million pounds in 1946.

Lactose is utilized industrially in several ways. It can be used as such; that is, as the purified solid sugar. Lactose can be used also as it occurs in whole milk and in dairy byproducts, such as skim milk, buttermilk, and whey. Lactose can be converted chemically into various derivatives, such as lactose esters and ethers, which have potential industrial importance. A fourth method comprises degrading the large lactose molecule—by heat, chemical agents, or microbiological organisms and agents—into smaller molecules. Most of the smaller molecules thus produced are chemicals of actual or potential usefulness.

Lactose was important during the Second World War. It was a valuable ingredient of vanilla and chocolate tablets and other concentrated foods distributed to the Armed Forces in all parts of the world. It was an important fuel in pyrotechnics; because it burns slowly and deepens the color of signals, it was used in various military and distress signals and in target identification candles.

WHEY, AN INEXPENSIVE DAIRY BYPRODUCT containing lactose as the principal organic constituent, is the best source of lactose.

About 10 billion pounds of whey is

produced annually in the United States. Approximately 9 billion pounds of whey is obtained as a byproduct in the manufacture of whole-milk cheese; 1 billion pounds is obtained similarly from cottage, pot, and bakers' cheese. A lesser quantity, 600 million pounds, of whey accompanies the production of casein. Casein whey is important, however, because it was the sole source of lactose in this country until about 1944.

The 10 billion pounds of whey produced each year contains about 500 million pounds of lactose. Because only about 4 percent of that lactose is actually separated and refined, there is plenty of whey for the manufacture of much larger quantities of the sugar. Other important constituents in the 10 billion pounds of whey are 50 million pounds of protein, 40 million pounds of nonprotein nitrogenous matter, 30 million pounds of fat, and 12,000 pounds of riboflavin (vitamin B_2).

Much of the whey is produced at widely scattered points; hence not all of it is available under conditions suitable for economic processing and utilization. Considerable quantities of it, however, are available in production centers under favorable conditions. In addition, at many centers of production, skim milk or whey could be concentrated and transported to nearby manufacturing areas at relatively low cost. In the manufacturing centers, where whey is obtained in volume, the utilization and disposal of this perishable and biologically active material present a problem.

Some types of whey are better than others for making lactose. For precipitating casein to obtain casein whey, either hydrochloric (muriatic) acid or sulfuric acid can be used. The casein whey produced with sulfuric acid is objectionable because of the difficulty of removing certain metal sulfates that impart cloudiness to the lactose solutions. Self-soured casein whey also is not a suitable raw material for making lactose because a considerable quantity of the lactose has been converted by fermentation into lactic acid. The same is true to a less extent for cottage-cheese whey. Muriatic casein whey is largely free of the objections, and so is considered a desirable raw material for making lactose.

Properties of common sugars

Sugar	*Melting point*	*Solubility at 25° C.*	*Sweetness*
	° C.	*Parts per 100 parts water*	*Percent*
α-Lactose.....	202	[1] 21.6	27
β-Lactose.....	252	[1] 21.6	>27
Sucrose.......	160–186	211.4	100
Glucose.......	146	82	50–60
Levulose......	102–104	....	100–150
Galactose.....	167	68.3	....
Maltose.......	102–103	108	60

[1] Equilibrium mixture of α- and β-lactose.

Several methods have been developed for recovering lactose from muriatic casein whey. In one of them the whey is heated to boiling in iron tanks with live steam. Lime is added during the heating until the acidity is about 0.5 percent or the pH value is 6.2. The coagulum is allowed to settle and the clear whey is evaporated in a multiple-effect evaporator to a concentration of 30 percent lactose or 20° Baumé. After being passed through a filter press, the sirup is concentrated further to about 40° Baumé by evaporation. The hot mass is dropped into crystallizing vats, where it is cooled and agitated slowly. The solid lactose thus obtained is freed from mother liquor by centrifugation and then washed with cold water. A second crop of crystals can be obtained by concentrating the mother liquor. The wet crude lactose should be either refined or dried promptly to prevent spoilage.

The recovery of crude lactose is usually 3 to 3.5 pounds per 100 pounds of whey. Further crystallization is required to produce refined, or United States Pharmacopoeia, lactose, the yield of which is 2.5 to 3 pounds per 100 pounds of whey. The less costly lactose of crude or technical grade is satisfactory for many purposes. At one time manufacturers usually attempted to obtain the maximum yield. Some manufacturers now find it profitable to make only partial recovery of about 2.5 pounds and to use the remaining mother liquor to make poultry feed.

The increased demands for lactose imposed in 1944 by the penicillin development were met principally by increasing production from cheese whey. Lactose can be made from cheese whey by concentrating it in a vacuum evaporator to 55 to 60 percent content of solids, cooling the concentrate with occasional stirring in a vat, centrifuging to separate the solid lactose, washing with cold water, and drying.

Cheese whey ordinarily must be gathered from several cheese factories; and, unless properly handled, it often ferments. So procurement is more costly, and the average yield is lower than that from casein whey.

The three grades of commercial lactose are crude, technical, and refined. The refined lactose is a white, odorless powder, at least 99.7 percent pure, as determined by the polariscope. The crude and refined grades sold for about 16 and 26 cents a pound, respectively, in December 1949. As sucrose and dextrose are usually available at less than 8 cents a pound, lactose is at a disadvantage for applications that can be met equally well by the other sugars.

Because β-lactose is more soluble than α-lactose, the normal form, and gives the impression of being sweeter, β-lactose is in demand for some uses. To meet the demand, methods for making β-lactose have been studied. Drying lactose solutions by the spray-drying process produces a mixture of the two forms in approximately the equilibrium ratio of 1.65 parts beta to 1 part alpha. The product dissolves much more rapidly than α-lactose, but it is hygroscopic and has poor wetting properties. The product made by drying lactose solutions on a drum drier contains as much as 90 percent of β-lactose if the most favorable drying conditions are used. Such a product has good wetting properties and is less hygroscopic than the spray-dried product and slightly more soluble initially than pure β-lactose. Other methods for making β-lactose have been developed, and its production in purified form has become an established industrial operation.

MUCH ATTENTION has been directed toward the mother liquor, or molasses, from lactose production to achieve maximum utilization of the byproducts. Early observations revealed that the material possesses marked growth-promoting properties that are accentuated by the addition of traces of crude rice polishings. At the time of the observations, vitamins were differentiated merely as fat-soluble or water-soluble. The evolution of vitamin technology gradually disclosed that lactose molasses contains numerous water-soluble vitamins, mainly riboflavin. Methods for the commercial recovery of natural crystalline riboflavin from this product were perfected about 1935, and for a short time this crystalline material was the only pure riboflavin commercially available. The natural product, however, did not long enjoy this status because of the persistence of research chemists, who rapidly synthesized riboflavin and initiated its mass production.

The byproducts of lactose manufacture, which contain valuable vitamins, minerals, and other food factors, are generally concentrated and used in poultry and animal feeds.

CHEMICALLY, lactose is called 4-*d*-glucose-β-*d*-galactopyranoside. It is a compound that has several hydroxyl groups, an acetal group, and a reactive hemiacetal or aldehyde group. Its chemical reactions are those that would be expected from a material having these functional groups. The normal form of lactose is the readily crystallizable α-hydrate; the β-form is more soluble than the α-form. Like other sugars, lactose dissolved in water has the characteristic of rotating plane-polarized light.

Lactose can be hydrolyzed with acids or enzymically with lactase, but not with maltase. The hydrolysis products are two other sugars, glucose and galactose, in equal parts. Glucose, made from starch, is an industrial product of great importance, but galactose has not yet been made commercially.

Having a reactive hemiacetal or aldehyde group, lactose is a reducing sugar. The reaction product of lactose and hydrogen cyanide is the corresponding aldehyde cyanohydrin. Lactobionic acid can be made from lactose by fermentation or by chemical oxidation of the aldehyde group. More extensive oxidation of lactose yields mucic and saccharic acids.

Both *d*-glucosan and *d*-galactosan have been made by the pyrolytic distillation of lactose. Depending on the conditions used, hydrogenation of lactose yields propylene glycol, hexanetriol, dulcitol, sorbitol, lactitol, and similar compounds. Various esters and ethers of lactose have been prepared.

Like many other sugars, lactose is a good substrate for microbiological processes and hence can be used to make various chemicals by fermentation. Of the many substances obtainable from lactose by fermentation, those that have been produced in moderate or high yields are lactic, citric, acetic, propionic, and butyric acids, ethanol, butanol, acetyl methyl carbinol, and riboflavin.

Lactose cannot compete with sucrose and dextrose as a sweetening agent because of its low solubility, hardness, dryness, and bland taste, and the slowness with which its crystals dissolve on the tongue. Although those properties have precluded the large-scale use of lactose as a sweetening agent, they have made possible its successful application in other fields. For example, the low degree of sweetness is essential in certain pharmaceuticals and special foods.

Prior to the commercial production of penicillin in 1944, more lactose was consumed in food preparations for infants, invalids, and the elderly than for any other purpose. Physicians prescribed it to make the lactose content of infant food comparable with that of human milk.

The pharmaceutical industry has always provided one of the principal outlets for lactose. Hospitals, dispensaries, and pharmacists need lactose for filling prescriptions. Tablets and pills must weigh at least 1 grain and powders 2 grains, regardless of the weight of the active ingredients. Lactose is usually selected to meet these weight standards because it is innocuous, soluble, odorless, and, in small quantities, virtually tasteless. Lactose may be used also as a coating on pills or tablets to mask the taste.

A comparatively large quantity of lactose is used in making compressed tablets and vitamin capsules, in which it serves largely as a vehicle. Lactose is good for that use because it blends well with other ingredients, does not absorb atmospheric moisture quickly, minimizes the disintegration of tablets in shipment, and prevents stickiness at high temperatures. Those characteristics accounted also for an important wartime demand, under Army and Navy contracts, for lactose to be used in vanilla and chocolate tablets and in ration packets distributed to the Armed Forces in all parts of the world, particularly in the hot humid areas of the Pacific.

As lactose in milk is the sugar selected by Nature for feeding infants, one might expect that lactose would be beneficial nutritionally. Although its specific nutritional advantages are not well understood, the general importance of lactose as a food is universally recognized. Lactose, unless fed in excessive quantities, accelerates growth in young animals better than other common sugars. It favors the production of riboflavin and vitamin B_6 in the intestine of the rat.

Certain lactose-rich whey products, such as plain condensed, sweetened condensed, or dried whey, may be used to make some candies, including fudge, caramel, and taffy. These lactose-rich products are particularly suitable for making fudge, because the lactose, by crystallizing, contributes to the desired texture.

Lactose, a complex condensation product of the sugars glucose and galactose, is more slowly broken down and utilized biologically than other common sugars. This slow rate of degradation and biological utilization may be important in several respects. For example, it has been suggested that the slow absorption of lactose may be a factor in the retention of glycogen, or animal starch, in the liver and muscles. There is evidence also that milk sugar increases the utilization of calcium and phosphorus, particularly in the young.

Whether or not the low rates of absorption and metabolism of lactose are important generally in biological processes, its superiority as a raw material in making penicillin by fermentation is undoubtedly due to slow metabolism. As the fermentation proceeds the alkalinity of the culture medium increases to a point where penicillium mold ceases to grow. Lactose is used as the acid-forming sugar in the medium to prevent excessive alkalinity. It is preferred for this purpose because it is utilized slowly by the organism and its effect is prolonged.

The development of penicillin has played a greater part than any other single factor in expanding the manufacture and consumption of lactose. Instead of the usual annual requirement of 6 to 7 million pounds, the lactose industry in 1944 was confronted with a need for 12 to 14 million pounds. The need was met largely by increasing production of lactose from cheese whey. New plants were built, existing facilities were improved and expanded, and refining was utilized more efficiently. Time was required to gear production to meet the greater demand. In the interim, with some minor exceptions, the entire milk-sugar supply was placed under allocation under War Food Order 95, effective on April 1, 1944. Through excellent cooperation between Government and industry, production to meet the new requirement was increased in 5 months, and it was feasible to suspend the allocation on September 1, 1944. The allocation was completely terminated a year later.

Largely as the result of penicillin manufacture, the estimated total production of lactose increased from 7.6 million pounds in 1943 to 13.3 million pounds in 1944, 18.8 million pounds in 1945, 23 million pounds in 1946, and 21 million pounds in 1947. Improvements have been made in penicillin manufacture during the past several years, so that less lactose is required. This probably was partly responsible for the drop in total production of lactose in 1948 to 17 million pounds. Lactose has proved superior to the cheaper sugars in making penicillin, and the use of crude lactose, which is relatively inexpensive, has been found feasible for the purpose. The need for penicillin, therefore, should keep the production of lactose at a high level for a long time.

Workers at the Eastern Regional Research Laboratory have shown that unsaturated esters and ethers of sugars, such as glucose methacrylate and sucrose and glycoside allyl ethers, can be used in making plastics and protective coatings. Lactose is more expensive than certain competing sugars, and therefore there is no good reason for believing that this potential outlet for it will prove important commercially.

An ester of lactose, the octanitrate, is an explosive, but this explosive has not proved important commercially. Calcium lactobionate-calcium bromide, made by electrolytic oxidation, is reputed to have particular merits as a sedative and for the alleviation of certain nervous disorders.

The production of mucic acid and saccharic acid from lactose on a pilot-plant scale was initiated in 1948. These two polyhydroxy dibasic acids undoubtedly can be used to make plasticizers, plastics, and other useful products. Probably the eventual commercial success of the acids will be detered largely by economic rather than emical factors.

Many other uses for lactose, such as silvering mirrors, preserving latex and oil cake, and giving a frosty appearance to certain bottled liqueurs, have been recorded, but these are of negligible commercial importance.

Because lactose as it is found in whey is much cheaper than in its solid, crystalline form, the utilization of lactose in whey is attractive economically. Although not suitable for the applications now met by solid lactose, lactose as it exists in whey can be utilized efficiently to make certain other materials by fermentation. Utilization by fermentation comprises transforming the lactose microbiologically into useful products, followed by recovery of the products from the fermented whey solution.

The chief factors that determine whether whey can be used economically for a commercial fermentation are the existence of an organism that will convert lactose efficiently into the desired product and the cost of whey in comparison with that of other carbohydrate materials, such as blackstrap molasses and starch hydrolyzates. Certain vitamins in whey give it an advantage in some instances.

Of the many substances obtainable from whey by fermentation, those that may be produced in yields sufficient to warrant consideration for commercial production are lactic, citric, propionic, and butyric acids, ethanol, butanol, acetyl methyl carbinol, and riboflavin. The only fermentation products now being manufactured from whey in the United States are lactic acid, ethanol, vinegar, riboflavin, butanol, and acetone.

Lactic acid is produced commercially from whey with a mixed culture of a lactobacillus and a mycoderm. The process is efficient because the yield is more than 0.9 pound of lactic acid for each pound of lactose.

The principal uses of lactic acid are in the leather industry, where it is employed to delime hides, and in foods and beverages. The function of lactic acid in food products is to give an acid taste to materials such as sherbets, fruit preparations, confections, pickles, and carbonated beverages. It is used also in bakery products, fruit pectin, mayonnaise, cheese manufacture, and various other food preparations (in brine of green olives, pickles, and sauerkraut, in preserves, jams, and jellies, fruit essences and extracts), and as a food preservative. It is used also for acidulating worts in brewing and for preventing growth of *Clostridium butyricum* in yeast manufacture.

Lactic acid is used in the production of phenolic resins, in cheese manufacture, instead of tartar bath in dyeing, as mordant in printing woolen goods, as solvent for water-soluble dyes, as reducer of chromic oxide in mordanting wool, and as flux for soft solder. Calcium lactate is employed in baking powder, foods, and pharmaceuticals to introduce calcium for nutrition. Sodium lactate is useful in industry because of its viscosity in solution and its ability to absorb and hold atmospheric moisture. Sodium lactate solutions have been substituted for glycerol in textile printing and in paper making. Because it corrects acidosis, yet does not produce alkalosis, it is sometimes used to overcome indigestion. It acts as a buffer in preventing undesirable reactions and decomposition of certain drugs in the alimentary tract. By a relatively new process, copper lactate can be used to electroplate almost any desired color. Iron lactate furnishes iron in nutrition. Various metal lactates have found use as mordants.

Lactic acid, a versatile chemical by virtue of its two functional groups, can be converted into various products of actual or potential industrial importance. These include solvents, plasticizers, alkyd resins, low-pressure laminating resins of the allyl type, vinyl polymers and copolymers, humectants, insect repellents, and acrylic esters. The acrylic esters can be transformed by polymerization or copolymerization into polymeric plasticizers, rigid plastics, and elastomers. The acrylic elastomers Lactoprene EV and Hycar PA are superior to most rubbers in resistance to deterioration caused by heat, oxidation, light, ozone, mineral oils, and repeated flexing.

Ethyl alcohol can be made from whey in 84 to 90 percent of the theoretical yield, by yeasts such as *Torula cremoris.* The protein, spent yeast, and distillation residues are suitable for feed. In making spirit vinegar from whey alcohol, the dilute alcohol is allowed to trickle over beech shavings or birch twigs impregnated with the acetic acid organism. Passage of air through the vinegar converter accelerates the fermentation.

The riboflavin content of whey can be increased by fermentation with *Clostridium acetobutylicum.* A yield of at least 30 micrograms of riboflavin per gram of whey can be obtained. About 30 percent of the lactose is converted during the fermentation into alcohols and acetone. Butanol, which is sufficiently valuable for recovery by distillation, comprises two-thirds of these compounds.

Butanol and acetone are in great demand as industrial chemicals and intermediates for making many commercial products, including esters of great value as solvents and plasticizers.

Of all the possible methods of utilizing lactose industrially, fermentation is one of the more attractive. Fermentation utilizes lactose in its cheapest form and converts it into versatile chemicals, which, in turn, can be transformed into a multitude useful materials.

Just as the present industry based on lactose was created largely by research, so will research bring new discoveries and design the future of the industry. Already chemistry has pointed the way to the transformation of lactose into adhesives, explosives, fibers, plastics, protective coatings, rubbers, solvents, plasticizers, pharmaceuticals, and similar products. But this is only the beginning. It now remains to improve known methods and materials, fit old products into new uses, and find new procedures and products. In particular, the chemist must accumulate much more information on lactose, find a way to lower its cost, and ascertain how its unique properties can be used to advantage and in spite of competition from cheaper sugars. The attainment of these goals will greatly enhance the value of lactose, give this sugar of animal origin its rightful position as a fundamental raw material, and provide the basis for the maximum utilization of lactose-rich dairy byproducts.

C. H. FISHER, *director of the Southern Regional Research Laboratory and formerly head of the carbohydrate division of the Eastern Regional Research Laboratory, has worked in Federal research laboratories since 1935. During the past decade, he has been primarily interested in developing new methods for utilizing carbohydrates as raw materials in making useful chemicals, plastics, and rubber substances.*

Composition of whole milk, skim milk, and whey

Constituent	*Whole milk*	*Skim milk*	*Whey*
Water	87.10–87.75	90.25–90.48	93.15–93.40
Fat	3.40– 3.90	.10– .20	.24– .35
Casein and albumin (protein)	3.20– 3.55	3.55– 4.00	.85– 1.00
Lactose	4.60– 5.10	4.70– 5.25	4.80– 5.09
Ash	.70– .75	.75– .80	.49– .65